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A History of the Sun's Luminosity, 0-460,000 BP, Based on the Geologic Record in Light of Recent Climate Theory

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Abstract

A solar luminosity index extending 460,000 years into the past is computed from ocean surface temperatures derived from the geologic record. It is estimated that the sun's luminosity fluctuated between 2% above to 5% below the current value over this period. The index shows pulses occurring at intervals of 75,000 to 120,000 years.

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It has been demonstrated that frequencies characteristic of variations in the Earth's orbital precession and obliquity are matched by similar frequencies in oxygen isotope ratios and micro fossils from ocean sediment cores. The orbital theory of climatic change predicts these frequencies should appear in the core records and so these results have been regarded as confirming the theory.[1-2] Energy balance climate models driven by orbital insolation variations, under the assumption of constant luminosity, can reproduce the small amplitude features of the ocean core records corresponding to precession and obliquity but not the large amplitude temperature spikes occuring at 100,000 yr intervals.[3] The agreement between the models and core records for the small amplitude short period orbitally driven features leads one to suspect that the explanation of the 100,000 year spikes may lie in some other source of insolation fluctuations such as the Sun.[4] There is independent evidence suggesting solar variability on a wide range of time scales. This includes the results from the neutrino experiments and the astronomical studies of solar type stars in clusters.[5,6] Supposing solar variability to be real one can in principle use climate models as a calibration to derive a scale factor converting the ocean temperature record to an index of solar luminosity.

Assuming constant solar luminosity the insolation variation due to orbital precession, obliquity, and eccentricity can be calculated accurately backwards in time for about a million years.[7,8] The main insolation change is in the difference between winter and summer hemispheric insolation and corresponds principally to the precession of the equinoxes which occurs with a period of about 23,000 years. The maximum amplitude of the 23,000 year variation in seasonal hemispheric insolation is about ten percent of the mean summer insolation. The amplitude of this cycle is modulated by the eccentricity and the obliquity with periods of 100,000 and 41,000 years respectively. The insolation fluctuations in the winter are opposite to those in the summer such that the annual average insolation is nearly constant. In fact the variation in annual global insolation is not more than one tenth percent under the assumption of constant luminosity. The published spectral analysis of the core records has stated that only ten percent of the variance in the ice volume records can be attributed to the 23,000 year period, whereas fifty percent of the variance is attributable to periods in the neighborhood of 100,000 years.[1] Herein lies a problem, for if the variations in the core records are entirely due to orbital insolation changes under the assumption of constant solar luminosity, then the earth's climate must respond in an exceedingly nonlinear and sensitive way to very small changes in the annual global insolation while remaining relatively insensitive to large fluctuations in the seasonal insolation. The ocean core temperature records bear little resemblance to the constant luminosity orbital insolation curves. Rather, they are characterized by relatively flat undisturbed stretches punctuated at approximately 100,000 year intervals by large temperature spikes. These spikes peak about five degrees above the average and last about 10,000 years. They are also simultaneous with a sudden decrease in the ice volume as measured by the oxygen isotope ratios. The contribution of the 100,000 year spikes to the temperature variance is even greater than in the ice volume data, which has a more sawtooth wave shape.

There does not seem to be a satisfactory climate-based explanation of the 100,000 year temperature spikes. The orbital theory has been quantitatively formulated using energy balance climate models driven by the calculated orbital variations in insolation. A recent study by Pollard[3] summarizes the outcome of these calculations (referring here to ice volume) as follows: "These simple models, then, seem to simulate correctly the phase (and approximate amplitude) of the higher frequency components of the core data, with the 40,000 year and 23,000 year responses tied to variations in obliquity and precession, respectively. However, the dominant 100,000 year sawtooth cycle of the data is not simulated by these models at all.

While it seems clear that orbital variations leave a record of climatic change, whether they are the principal cause of climatic change would seem to be open to debate. Given that ten percent changes in seasonal hemispheric insolation produce ten percent of the variance in the records it is difficult to explain how less than one tenth percent changes in annual global insolation can produce fifty percent of the variance. Unless there is some very complicated climatological trigger mechanism present but not included in the models, which has not been demonstrated, a simpler conclusion is that the experimental and computational work on the orbital hypothesis is essentially correct and that the discrepancies in the record are due to other sources of insolation fluctuations.

One obvious possible source of fluctuation is the Sun itself. Opik has worked on solar variability since the early 1940's and published many articles on the subject.[4] In his attempt to deduce a historical record of past solar luminosity fluctuations, he was led in the early 50's to construct an energy balance description of the earth's climate from which he related average global temperatures to solar luminosity.[9] Opik's explanation of solar variability relies on periodic convective instability in the solar core resulting from depletion of hydrogen and the resulting changes in opacity of the core. This mechanism has a time scale of millions of years - long enough to account for the major ice ages but too long to account for the 100,000 year spikes. The latter he attributes to fluctuations in the Sun's convective envelope.

The idea of variable solar luminosity on larger time scales would probably not receive serious attention were it not for the solar neutrino experiments of Davis and Evans.[5,10] These experiments give a direct measurement of the rate of nuclear reactions in the solar core.

The experiments have established a very low value for the neutrino flux - much lower than predicted by the standard steady state solar models. This has prompted various modifications to the steady solar models, but the lowest calculated flux is still greater than measured. The basic problem with the steady state model is that the rate of energy radiated to space by the Sun must equal the rate of energy production in the solar core putting a lower limit on the rate of helium production and the number of neutrinos emitted.

Because of this there is motivation to abandon the steady state hypothesis, since then the energy radiated at any given time will not necessarily equal the nuclear energy release in the core.[11] In this view the Sun, at the present time, is coasting on its stored gravitational and thermal energy, with its nuclear power source on low.

Besides instigating a spate of new solar models and theories based on instabilities or transients the neutrino results have prompted attempts to look for other experimental evidence of variability.[12-15] Sagan has pointed out that if luminosity fluctuations occur in the Sun then one should also expect them in other solar type stars.[6] Using color-magnitude data from star clusters he measured a dispersion corresponding to a total excursion in luminosity of about 15% which is in the range consistent with the climatic record.

The theoretical time scale of the fluctuations generally envisioned for the solar core are on the order of millions of years. Very recently, however, evidence has been uncovered linking variability to much shorter time scales.[16] Davis' neutrino measurements show a variability, over a period of years substantially exceeding the observational error of each measurement. Sakurai has compared the time variation of the measured neutrino flux with the time variation of the sun spot number after subtracting out the 11 year trend. The relative sun spot number has a characteristic 25 month period which is believed to be produced by some instability associated with hydromagnetic convective motion beneath the photosphere. Superimposed curves of relative sun spot number and neutrino counting rate show considerable similarity. From this Sakurai infers that the neutrino production in the solar core is also related to the convective motions responsible for the 25 month relative sun spot variation.

The solar data mentioned gives evidence, independent of the Earth's climate history, that the Sun's luminosity fluctuates on very wide time scales. It would seem that the recent experimental results on the effect of orbital perturbations on climate can offer a clue to solar variability, for if we accept the experimental and computational climate modelling work on the Milankovitch hypothesis to be essentially correct, then we must look elsewhere for the source of unexplained variations in the ocean core records. In view of the present uncertainty in solar theory it would seem that variable solar luminosity is a likely candidate. Viewed in this light, what the orbital work has done for us is to provide us with a theoretically and experimentally consistent calibration of the earth's climatological response to a known driving function, from which we may determine the magnitude of other effects, in particular variations in the Sun's luminosity. To read the record of the past we need to find the appropriate scale factor to convert from ocean temperature to luminosity.

The results of sensitivity studies with climate models are often expressed in terms of a sensitivity parameter given by the solar constant or luminosity multiplied by the derivative of global average temperature with respect to the solar constant or luminosity. The main problem is determining what is the most realistic estimate for the climate sensitivity parameter. Published values range all the way from 70 to 400 C.[17-23]

It is possible to rule out some models as being more unlikely than others because they do not agree with the planetary albedo and infrared flux data that have been gathered by satellites. Comprehensive analysis of this data has only recently become available.[24] Models that best fit the available radiation measurements and their variations with latitude yield sensitivity parameters in a range from 125 to 190.[25-26] I favor the lower value because it is more consistent with the difficulty for a permanent ice cover to develop over open ocean areas than over continental areas. Having determined a value for the sensitivity parameter one can compute a luminosity index using the inverse of the sensitivity parameter as the scale factor.

The ocean surface temperature record of Hays, Imbrie, and Shackleton is derived from cores at approximately 45S latitude 85E longitude.[1] The temperature sensitivity is greater at the poles than at the equator, but for models in the more likely sensitivity range, the sensitivity for the temperature at 45S latitude is close to that of the global average temperature. Examination of the existing meridional distribution of ocean surface temperature at the longitude of the core samples reveals no large discontinuities or fronts either in summer or winter.[27] Discontinuities could spoil the correlation between temperature and luminosity because they could produce large temperature fluctuations from small shifts in position.

A solar luminosity scale based on a sensitivity parameter of 125 C, has been added to the ocean temperature record converting it to a solar luminosity history, as shown. The index might also be viewed as a probable upper bound on solar luminosity fluctuations because it is based on a sensitivity parameter at the low end of the majority of the published values and at the low end of my estimated range of more likely values.

To summarize, solar theory seems to be in a state of uncertainty and flux. On the other hand the orbital theory of climatic change seems to be in good shape. It accounts for the variations due to precession and obliquity insolation changes much as current climate theory would predict. Yet it does not easily account for the 100,000 yr interval temperature spikes. Perhaps instead of trying to force the orbital theory into accounting for all aspects of the record which it does not seem to easily do, we should accept the theory and look outside it for those aspects it does not explain. Insolation fluctuations due to Solar luminosity changes would seem to be one of the more likely possibilities.

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Figure Captions

Figure 1:

Top curve: The meridionally averaged annual insolation for the Northern Hemisphere, based on a constant luminosity. The curve is computed from Vernekar's 1968 insolation tables scaled to a solar constant of 1360 WM^{-2}.

Middle curve: The meridionally averaged summer insolation for the Northern Hemisphere, based on a constant luminosity. The curve is computed from Vernekar's 1968 insolation tables.

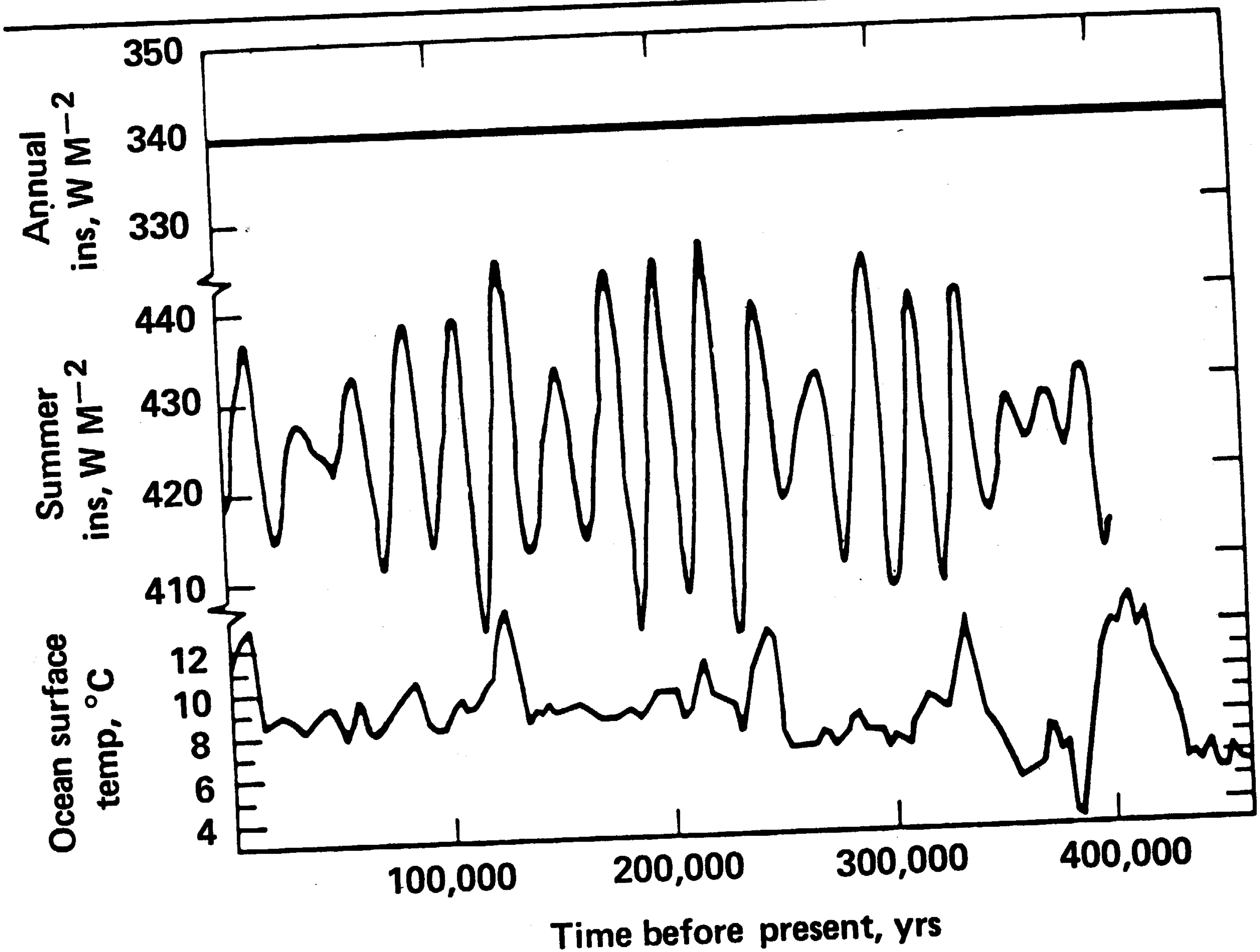
Bottom curve: The ocean surface temperature record at 45S latitude 85E longitude (after Hays, Imbrie and Shackleton 1976)

Figure 2:

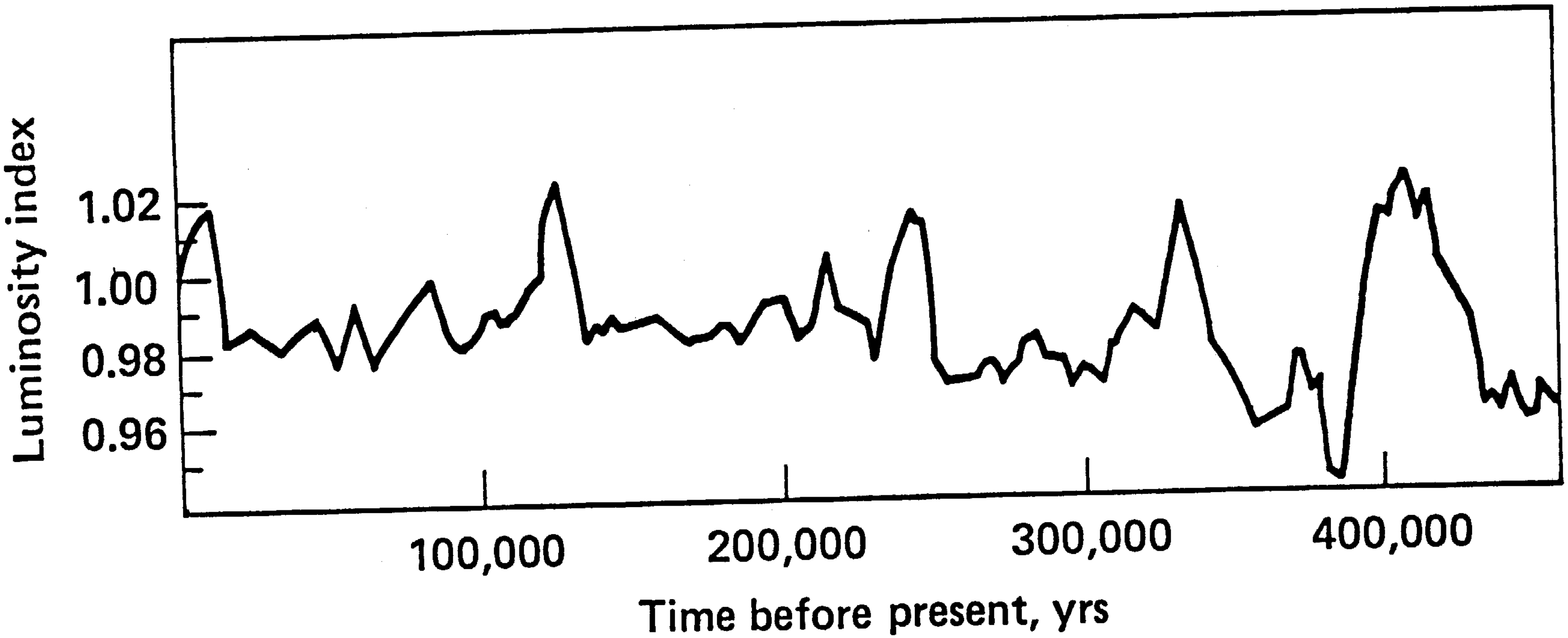
Solar luminosity record normalized with repect to the present luminosity (based on core data of Hays, Imbrie and Shackleton 1976).

Notation

	Climate sensitivity parameter
L	Sun's luminosity
s	Solar constant - the sun's radiant energy flux at the earth's orbital radius
T	Global average temperature of the earth



Annual ins, W M^{-2}
350
340
330
Summer ins, W M^{-2}
440
430
420
410
Ocean surface temp, °C
12
10
8
6
4
100,000
200,000
300,000
400,000
Time before present, yrs



Luminosity index
1.02
1.00
0.98
0.96
100,000
200,000
300,000
400,000
Time before present, yrs